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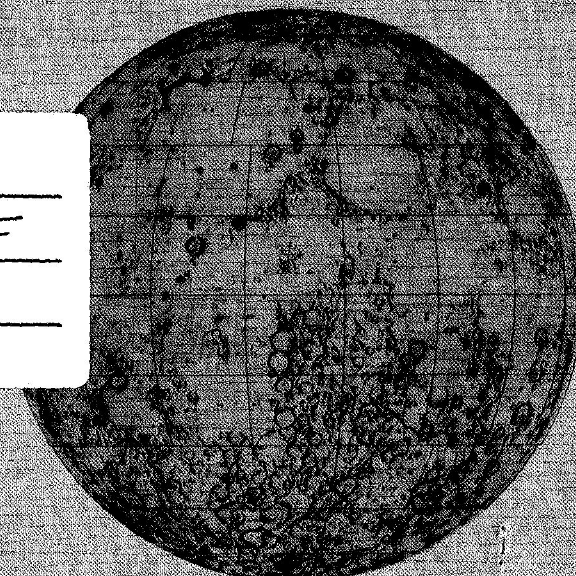
ASTROGEOLOGIC STUDIES

ANNUAL PROGRESS REPORT

July 1, 1965 to July 1, 1966



SUMMARY

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

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ANNUAL PROGRESS REPORT

July 1, 1965 to

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SUMMARY

December 1966

This report concerns work done on behalf of the National Aeronautics and Space Administration.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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INTRODUCTION

This Annual Report is the seventh of a series describing the results of research conducted by the U.S. Geological Survey on behalf of the National Aeronautics and Space Administration under contract R-66. Prepared by the Astrogeologic Studies Section of the Branch of Astrogeology, it covers the period July 1, 1965, to July 1, 1966, and is in four volumes corresponding to four areas of research: Part A, Lunar and Planetary Investigations, with map supplement; Part B, Crater Investigations; Part C, Cosmic Chemistry and Petrology; and Part D, Space Flight Investigations, with map supplement. This additional volume summarizes the papers in Parts A, B, C, and D.

Long-range objectives of the astrogeologic studies program are to determine and map the stratigraphy and structure of the Moon's crust, to work out from these the sequence of events that led to the present condition of the Moon's surface, and to determine the processes by which these events took place. Work being carried out that leads toward these objectives includes a program of lunar geologic mapping from both telescopic and spacecraft photographs; studies on the discrimination of geologic materials on the lunar surface by their photometric, polarimetric, and infrared properties; field studies of structures of impact, explosive, and volcanic origin; laboratory studies on the behavior of rocks and minerals subjected to shock; and study of the chemical, petrographic and physical properties of materials of possible lunar origin and the development of special techniques for their analysis.

Part A, Lunar and Planetary Investigations, consists of four sections of text and a map supplement. Preliminary maps of seven quadrangles at a scale of 1:1,000,000 are included in the map supplement; five are located in the northwest quadrant of the Moon and two in the southeast. These maps represent the first extensions of lunar geologic mapping beyond the equatorial belt (lat 32° N.-32° S., long 70° E.-70° W.) that was covered in previous years. Three maps in the equatorial belt at a scale of 1:500,000 are also included in the map supplement, and structural maps of two others are shown as text figures.

The first text section is a collection of geologic summaries of eight maps at a scale of 1:1,000,000 published or in press during the present report period. In addition to these, two other quadrangle maps were published in this period, Montes Apenninus and Aristarchus, but their geology was summarized in previous annual reports in articles by Hackman (1962-63 rept., p. 1-8) and Moore (1962-63 rept., p. 33-45; 1963-64 rept., p. 42-51). Some of the eight quadrangle maps summarized in this section are accompanied by summary texts in their published form: Copernicus, Hevelius, Mare Humorum, Mare Vaporum, and Seleucus. The others--Julius Caesar, Pitatus, and Mare Serenitatis--do not have summary texts in their published form. Two quadrangles, Julius Caesar and Mare Vaporum, are geologically similar and thus are discussed in one article in this report.

The second section includes two topical studies, summaries or special studies of the geology in three of the seven quadrangles covered by preliminary maps in this report, and a structural study of two 1:500,000-scale quadrangles.

The third section comprises seven articles describing studies in lunar and planetary physics that are in support of the geologic mapping program.

The fourth section is an extensive summary of lunar stratigraphic concepts and of stratigraphic units that appeared on preliminary maps produced through the annual report period preceding this one and on revised published versions of some of these same maps.

Part B, Crater Investigations, contains the results of field and laboratory studies of craters and related phenomena. Field investigations have been made of naturally formed craters and roots of craters: (1) the Flynn Creek structure in east Tennessee, (2) the Sierra Madera structure in west Texas, (3) the Manicouagan Lake structure in Quebec, Canada, and (4) the Moses Rock diatreme in Utah. The first three are thought to be eroded impact structures; the fourth is the root of a maar-type crater.

Results of two experimental studies of impact craters are reported in (1) "Craters Produced by Missile Impacts," and (2) "Hypervelocity Impact Craters in Pumice"; a third paper provides a compilation of data on craters formed by explosives. Another paper describes a new technique for field explosive shock experiments.

Summaries of field and laboratory studies of shock-induced changes in rocks are given in three papers: (1) "Impact Metamorphism," (2) "Nickel-Iron Spherules from the Aouelloul Glass of Mauritania, Africa," and (3) "Influence of Stress History on Low-Temperature Thermoluminescence of Halite."

Part C, Cosmic Chemistry and Petrology, includes reports on techniques of study, analysis, and interpretation of data on materials of known or suspected extraterrestrial origin. The results of a study in which metallic spherules and glass in tektites are compared with spherules and glass in impactites are presented. Conclusions are drawn as to the partial pressure of oxygen during tektite formation. New chemical analyses of the Martha's Vineyard and Georgia tektites reveal that these tektites are genetically related to the Texas tektites (bediasites) and that they were probably formed by the same event. A study done in cooperation with the Smithsonian Institution reveals that troilite lamellae in iron meteorites crystallized from a melt, and that some of the meteorites containing these lamellae apparently cooled extremely rapidly. Further data are presented on the search for cosmic dust as part of the Luster Project, done in cooperation with NASA. A review article on the latest techniques available in geochemical analysis is included. The work was done in cooperation with the Branch of Analytical Services, U.S. Geological Survey. Finally, new techniques are presented for the analysis of trace amounts of Cs, Hf, and Ta by neutron activation and of Zn and Ag by spectrography.

Part D, Space Flight Investigations, includes reports on geologic analysis and mapping from Ranger photographs, research on methods of Ranger photogrammetry, an analysis of small lunar craters by comparison with experimentally produced impact and explosion craters, and a sample of the preflight geologic reports prepared for the sites photographed by Lunar Orbiter I.

The following reports were published during the period July 1, 1965 to July 1, 1966:

Brett, Robin, 1966, Cohenite in meteorites--A proposed origin: Science, v. 153, no. 3731, p. 60-62.

______ 1966, Metallic spherules in impactite and tektite glasses [abs.]: Am. Geophys. Union Trans., v. 47, no. 1, p. 145.

Carr, M. H., 1965, Geologic map and section of the Timocharis region of the Moon: U.S. Geol. Survey Misc. Geol. Inv. Map I-462.

______ 1966, Measurement of the velocity of high-amplitude shock waves in rock materials by means of strain gages, in Geological Survey research 1966: U.S. Geol. Survey Prof. Paper 550-B, p. B99-B103.

Cassidy, W. A., Willar, L. M., Bunch, T. E., Kohman, T. P., and Milton, D. J., 1965, Meteorites and craters of Campo del Cielo, Argentina: Science, v. 149, no. 3688, p. 1055-1064.

Chao, E. C. T., Merrill, C. W., Cuttitta, Frank, and Annell, Charles, 1966, The Aouelloul crater and the Aouelloul glass of Mauritania, Africa [abs.]: Am. Geophys. Union Trans., v. 47, no. 1, p. 144.

Duke, M. B., 1966, The Shergotty meteorite--Magmatic and shock metamorphic features [abs.]: Am. Geophys. Union Trans., v. 47, no. 3, p. 481.

Eggleton, R. E., 1965, Geologic map of the Riphaeus Mountains region of the Moon: U.S. Geol. Survey Misc. Geol. Inv. Map I-458.

Gault, D. E., and Moore, H. J., 1965, Scaling relationships for microscale to megascale impact craters: Hypervelocity Impact Symposium, 7th, Tampa, Fla., 1964, Proc., v. 6, p. 341-351.

Hackman, R. J., 1966, Geologic map of the Montes Appeninus region of the Moon: U.S. Geol. Survey Misc. Geol. Inv. Map I-463.

Milton, D. J., 1966, Structure of the Henbury meteorite craters, Australia [abs.], in Conference on shock metamorphism of natural materials, April 14-16, 1966: Greenbelt, Md., Goddard Space Flight Center, NASA, p. 36.

Milton, D. J., and Michel, F. C., 1965, Structure of a ray crater at Henbury, Northern Territory, Australia, in Geological Survey research 1965: U.S. Geol. Survey Prof. Paper 525-C, p. C5-C11.

Moore, H. J., 1965, Geologic map of the Aristarchus region of the Moon: U.S. Geol. Survey Misc. Geol. Inv. Map I-465.

Roddy, D. J., 1966, Carbonate deformation at a probable impact crater at Flynn Creek, Tennessee [abs.]: Am. Geophys. Union Trans., v. 47, no. 3, p. 493-494.

______ 1966, Minimum energy of formation for a probable impact crater at Flynn Creek, Tennessee [abs.]: Am. Geophys. Union Trans., v. 47, no. 3, p. 482.

______ 1966, An unusual dolomitic basal facies of the Chattanooga shale in the Flynn Creek structure, Tennessee [abs.]: Am. Mineralogist, v. 51, nos. 1-2, p. 270.

Shoemaker, E. M., 1966, Interpretation of the small craters of the Moon's surface revealed by Ranger VII: Internat. Astron. Union, 12th Gen. Assembly, Hamburg 1964, Trans., v. XIIB, p. 662-672.

______ 1966, Preliminary analysis of the fine structure of the lunar surface in Mare Cognitum, in Hess, W. N., Menzel, D. H., and O'Keefe, J. A., eds., The nature of the lunar surface: IAU-NASA Symposium, 1965, Proc., Baltimore, Johns Hopkins Press, p. 23-77.

______ 1966, Progress in the analysis of the fine structure and geology of the lunar surface from the Ranger VIII and IX photographs, in Caltech-JPL Lunar and planetary conference, 1965, Proc.: California Inst. Technology, Jet Propulsion Lab., Tech. Memo. 33-266, p. 30-31.

______ 1966, Structure of the Jangle U and Teapot Ess nuclear explosion craters [abs.], in Conference on shock metamorphism of natural materials, April 14-16, 1966: Greenbelt, Md., Goddard Space Flight Center, NASA, p. 22.

Shoemaker, E. M., 1966, When the irrestible force meets the immovable object: Engineering and Science, v. 29, no. 5, p. 11-15.

Shoemaker, E. M., Batson, R. M., and Larson, K. B., 1966, An appreciation of the Luna 9 pictures: Astronautics and Aeronautics, v. 4, no. 5, p. 40-50.

Shoemaker, E. M., and others, 1965, Report of Geology Working Group, in NASA 1965 summer conference on lunar exploration and science, Falmouth, Massachusetts, July 19-31, 1965: U.S. Natl. Aeronautics and Space Adm. Spec. Pub. 88, p. 77-160.

______ 1966, Progress in the analysis of the fine structure and geology of the lunar surface from the Ranger VIII and IX photographs, in Ranger VIII and IX, pt. II--Experimenters' analyses and interpretations: California Inst. Technology, Jet Propulsion Lab. Tech. Rept. 32-800, p. 249-337.

Wildey, R. L., 1966, Measuring the shape of the Moon: Sky and Telescope, v. 21, no. 3, p. 147-150.

SUMMARY OF PART A

Lunar investigations through this report period have been based on geologic mapping of the Moon from telescopic data at scales of 1:1,000,000 and 1:500,000. This mapping is supplemented by mapping at larger scales from Ranger spacecraft photographs and analysis of Surveyor spacecraft photographs; these studies are described in Part D, Space Flight Investigations. Geologic maps of six quadrangles at a scale of 1:1,000,000 have been published and reported on previously (fig. 1). An additional eight maps, published recently or in press, are reported on in Part A. Preliminary maps of 14 additional quadrangles, as well as of the quadrangles for which maps have been published or are in press, have been transmitted to the National Aeronautics and Space Administration previously. Preliminary maps of seven more quadrangles at a scale of 1:1,000,000 are included in the map supplement to Part A: Cassini, by N. J Page; Sinus Iridum, by G. G. Schaber; Plato, by J. W. M'Gonigle and D. L. Schleicher; J. Herschel, by G. E. Ulrich; Rümker, by R. E. Eggleton and E. I. Smith; Maurolycus, by N. D. Cozad and S. R. Titley; and Rheita, by D. E. Stuart-Alexander. Three preliminary maps of quadrangles at a scale of 1:500,000 are also included (fig. 2): Reinhold (AIC 58D), by Jerry Harbour; Euclides P (AIC 57C), by M. N. West; and Flamsteed (AIC 75A), by S. R. Titley. The structure of two additional 1:500,000 quadrangles, Triesnecker (AIC 59C) and Hipparchus (AIC 77B), by T. W. Offield, is shown in text figures and described. By the end of fiscal year 1967, preliminary colored maps of nine additional 1:1,000,000 quadrangles and several additional 1:500,000 ones will be completed, and with them the part of the Moon accessible to telescopic study will

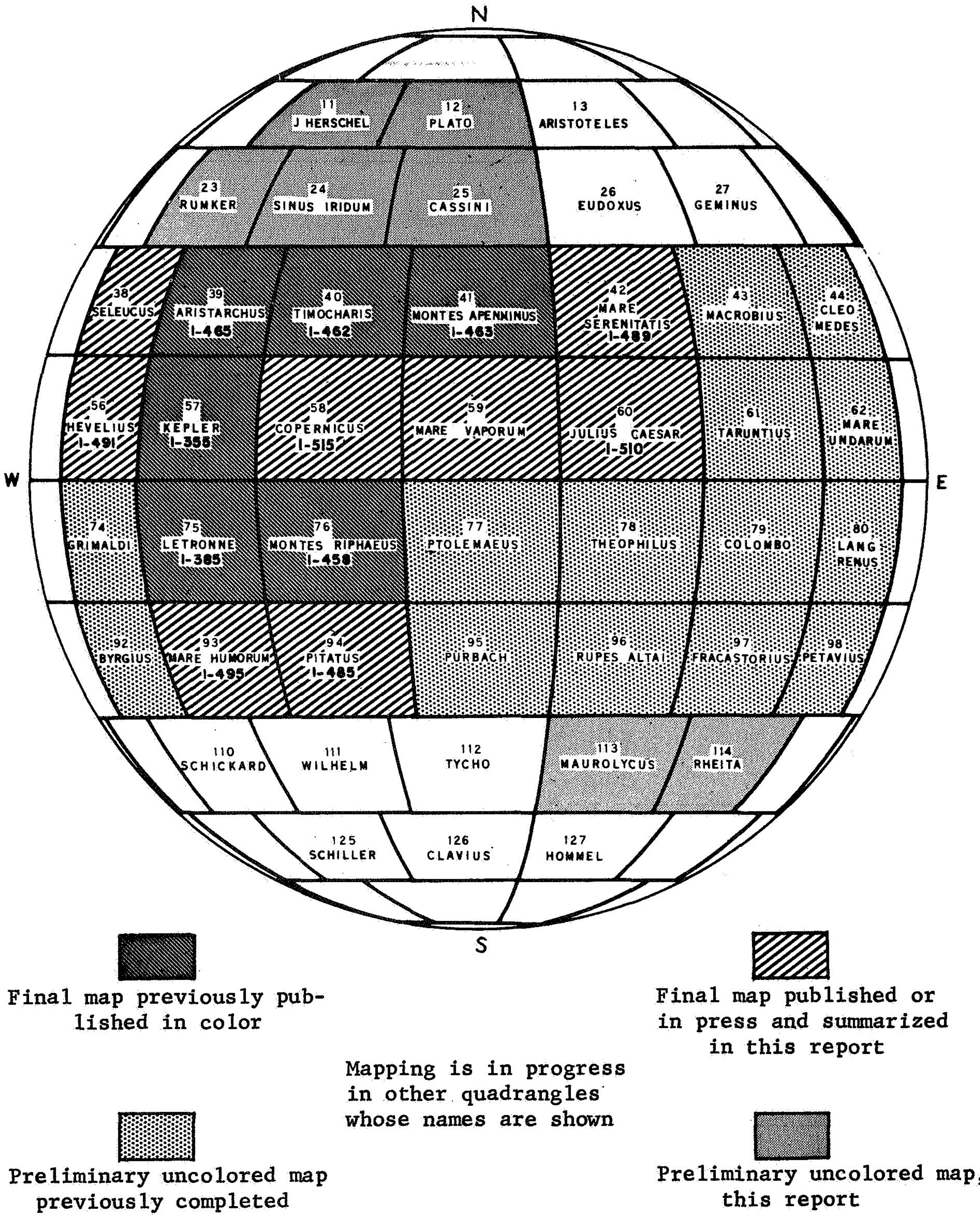

Figure 1.--Index map of Moon showing status of geologic mapping at a scale of 1:1,000,000.

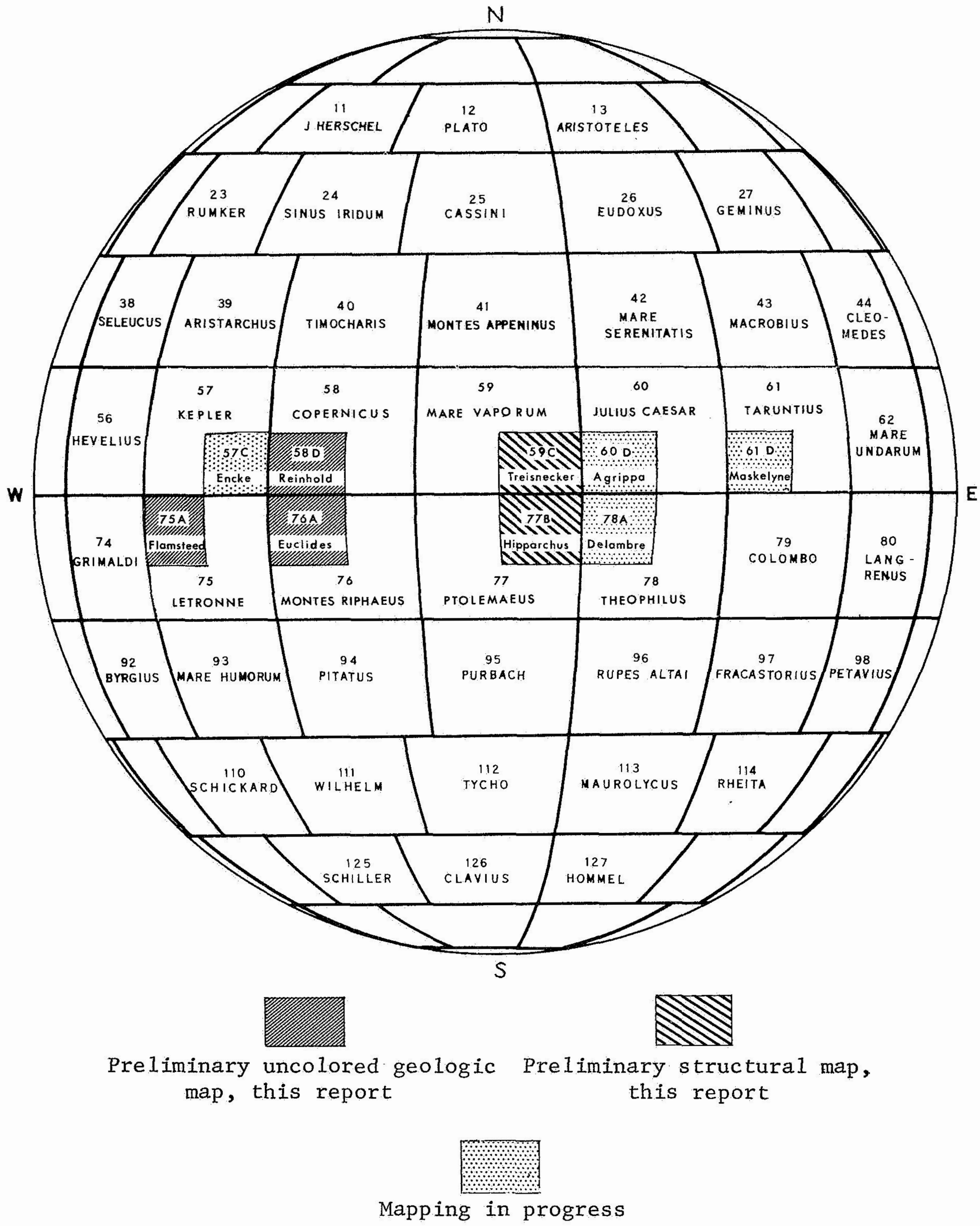

Figure 2.--Index map of Moon showing status of geologic mapping at a scale of 1:500,000.

have been completely mapped. Subsequent work, other than preparation of the preliminary maps for publication, will be based on Lunar Orbiter data.

Section I

The first section includes geologic summaries of eight quadrangles that were published or in press during the current report period and immediately thereafter. These include Pitatus, by N. J. Trask and S. R. Titley; Mare Serenitatis, by M. H. Carr: Mare Humorum, by S. R. Titley; Hevelius, by J. F. McCauley; Copernicus, by H. H. Schmitt, N. J. Trask, and E. M. Shoemaker; Seleucus, by H. J. Moore; Julius Caesar, by E. C. Morris and D. E. Wilhelms; and Mare Vaporum, by D. E. Wilhelms.

Three of the quadrangles--Copernicus, Mare Vaporum, and Julius Caesar--are in that part of the equatorial belt that includes potential targets for early Apollo missions. Many Lunar Orbiter photographs of these areas were obtained after telescopic mapping had been completed. Many of the geologic units and structures in these three quadrangles and in an adjacent one--Mare Serenitatis--were studied in early lunar geologic work and formed the basis for much of the lunar stratigraphic column. Structures and stratigraphic units related to the basin of Mare Imbrium are dominant. The early interpretation of the Fra Mauro Formation as impact ejecta from the Mare Imbrium basin is apparently still valid. A widespread unit older than the mare material is light plains-forming material (Cayley Formation), which may be identical in composition and original albedo with mare material but is now brighter because of more intense cratering. The principal new results from the most recent mapping of the four quadrangles concern units younger than the mare material of the Procellarum Group, in the Eratosthenian and Copernican Systems. Some of these younger units are probably composed of volcanic materials, and lunar volcanism seems to have continued into relatively recent times. One such young volcanic unit is a dark terra-mantling unit, Sulpicius Gallus Formation, that was previously interpreted as an intrinsically dark facies of the Fra Mauro Formation but is now believed to be composed of pyroclastic material. The time of formation of the Sulpicius Gallus appears to span the Imbrian-Eratosthenian boundary. Many dark-halo craters of probable volcanic origin lie within the Sulpicius Gallus Formation. Some dark units of mare material in the Mare Vaporum quadrangle are younger than the Procellarum Group, and similar units in the other areas may be post-Imbrian in age. Most of these dark mare materials as well as young non-mare volcanic materials occur near basin margins, which may therefore be among the most recently active lunar volcanic zones. The existence of relatively old marelike light plains-forming materials and of relatively young dark ones casts doubt on an earlier hypothesis of a single episode of mare formation.

New data have also been gathered about crater materials. Thermal anomalies at eclipse measured by Boeing Scientific Research Laboratories seem to correlate fairly well with age criteria developed previously by the Geological Survey. High anomalies are most commonly observed in craters that have either bright rays or dark halos and that have been assigned to the Copernican System, and low anomalies in craters that have moderate-albedo rim material and no discrete rays or very faint rays and so have been designated Eratosthenian. This apparent correlation has been used to date craters whose albedo properties are not clearly age related, such as craters that have bright rim material but lack detectable discrete rays. Several probable volcanic craters for which age criteria have previously been lacking also have high anomalies and thus are presumably young. Some light-rimmed craters on terra have low anomalies, whereas some craters with rims of moderate albedo on mare have high anomalies, suggesting that source material has an effect on the albedo of rim material. Detailed studies on superior full-Moon photographs of the albedo pattern of Copernicus have also shown a dependence of albedo on source rock.

Two quadrangles--Pitatus and Mare Humorum in the southwest part of the Moon--cover the Humorum basin, part of Mare Nubium, and a small part of the southern lunar highlands. Materials in this area cannot be directly dated relative to the Fra Mauro Formation, but most are considered pre-Imbrian because of the high density of superposed large craters. The Humorum basin is interpreted as pre-Imbrian in age because of this high density of craters on its rim and because its rim and related peripheral structures are subdued relative to analogous structures of the Imbrium basin. The Humorum basin is surrounded by hummocky material that resembles the Fra Mauro Formation and may be ejecta from an impact that created the Humorum basin; the material is named the Vitello Formation. Two partly interbedded units in the Humorum and Pitatus quadrangles are younger than the Humorum basin but older than the mare material of the Procellarum Group that fills this basin. One unit is composed of crater materials (Gassendi Group) and the other of light plains-forming materials. The Gassendi Group probably includes pre-Imbrian as well as Imbrian craters because Gassendi Group craters are more numerous than the analogous Archimedes-type craters of Imbrian age in the Imbrium basin. The light plains-forming material is similar to the Cayley Formation of Imbrian age in and near the Imbrium basin, but the material in Humorum can be dated no more closely than pre-Imbrian or Imbrian. A younger unit of interest is the Doppelmayer Formation, a dark blanketing unit much like the Sulpicius Gallus Formation in the central part of the Moon and probably of the same age.

The Hevelius quadrangle, at the west border of Oceanus Procellarum and adjacent to the equator, includes three distinct topographic provinces. The westernmost province is part of an extensive cratered terra that extends outside the quadrangle to Mare Orientale and may be covered by a blanket of impact ejecta from the Orientale basin. This blanket, the Hevelius Formation, is thin in the quadrangle and only partly subdues large features such as the crater Hevelius. The second province, in the center of the quadrangle, is the mare plain of Oceanus Procellarum. Two mare units have been mapped: a lighter one of the Procellarum Group and a darker one that is very likely younger than the Procellarum and that could be Eratosthenian or Copernican. The third province, in the northeast, is an undulating plateau upon which domes of two types and ages--older low domes and younger steep ones--are superposed; the plateau- and dome-forming materials are called the Marius Group and assigned an Eratosthenian age. An additional unit of interest is a thin dark blanketing unit, the Cavalerius Formation of Copernican age, which covers parts of the first and second provinces and is the unit on which the Soviet spacecraft Luna 9 may have landed.

The principle feature of the Seleucus quadrangle, in the northwest quadrant of the Moon and north of the Hevelius quadrangle, is the Aristarchus plateau. The most widespread unit on the plateau, the Vallis Schröteri Formation of Eratosthenian and Copernican age, is probably of volcanic origin. This unit was recognized earlier in the adjacent Aristarchus quadrangle and has been subdivided in the Seleucus quadrangle. The principle members are a hummocky unit believed to result from superposition of thin cover on older terrain and a younger dark smooth plains-forming member that fills depressions in the hummocky member. Three types of landforms that are probably volcanic constructional features are also present and are part of the formation. Some terrain mapped in the Aristarchus quadrangle as Fra Mauro Formation is now interpreted as Vallis Schröteri Formation. Since other units of the plateau--the Harbinger Formation and materials forming the sinuous rille Vallis Schröteri and its domelike source the Cobra's Head--are also of probable volcanic origin and are relatively young, the plateau is certainly one of the most recently active volcanic regions on the Moon and may still be active today. A clear-cut example of very young mare material, apparently extruded from a long straight fracture, is present on the southeast flank of the Copernican crater Lichtenberg, where dark mare material has covered the crater's ejecta and rays.

Section II

The first two papers in section two are topical studies. In one, G. I. Smith describes several characteristics shared by two young fault grabens in southeast California and the lunar rilles Rima Ariadaeus and Rimae Hypatia I and II. The bounding scarps presumably reflect the patterns of faults on the margins of the lunar rilles, as they do in the terrestrial grabens. The scarps are sinuous in detail but straight in overall trend, and those on opposite sides tend to be equidistant and parallel throughout their length. The boundary faults are not continuous single fractures but a series of nearly alined, overlapping en echelon fractures. The absolute dimensions and proportions of the rilles and grabens are mostly different, but the width-to-depth ratios in all the features are similar. The lunar as well as the terrestrial features are probably grabens produced by an extension of the crust, though the fundamental cause of the extension may vary with each graben. The lunar rilles are probably tectonic, which means that moonquakes may occur during their formations. Moreover, because the lunar grabens have different ages, extent, and orientation, the lunar stress and strain fields apparently migrate, and this implies a mobile subcrustal zone. The rilles are of additional interest because their walls may provide exposures of stratified bedrock.

In the second topical study, S. R. Titley discusses the possibility that seismic activity may have acted in conjunction with other agents, such as micrometeorites and secondary debris ejected from craters, to modify and erode the lunar surface. He evaluates the possible sources of lunar seismicity and concludes that activity with sufficient energy to affect the surface morphology of loose materials could be produced by impact events alone but that endogenous seismicity may also be present. The result of impact seismicity is the acceleration of erosional processes through compaction, shaking, and lateral and downslope mass movement. By means of a simplified formula from soil mechanics, Titley has calculated the accelerations required to start movement on slopes of various angles. Crater forms and the surface texture shown on the Ranger photographs strongly suggest, by terrestrial analogy, that modification of the surface by slumping, creep, and differential compaction has occurred.

Three papers discuss results of preliminary mapping of the Plato, Cassini, and J. Herschel quadrangles in the northwest part of the Moon. The area covered includes the northern half of the Mare Imbrium basin and its peripheral structures. Maps of two additional quadrangles, Rümker and Sinus Iridum, are included in the supplement. This region is at a distance from the center of the Imbrium basin comparable to that of regions in which lunar stratigraphic units were first recognized and in which most of the previous years' mapping efforts have been concentrated.

J. W. M'Gonigle and D. L. Schleicher, mapping the Plato quadrangle, and N. J Page, mapping the Cassini quadrangle, recognize hummocky terrain similar to that mapped as the Fra Mauro Formation in the areas to the south but find evidence that the morphology of much of this northern terrain is of structural as well as of depositional origin. There are fewer structures of the Imbrian radial system (Imbrian sculpture) in the north than in the south. Light plains-forming material similar to the Apennine Bench Formation and dark plains-forming mare material are also present, and the age relation of most occurrences is like that determined in other areas: the darker units are the younger ones.

The Cassini quadrangle covers a low area between the Montes Caucasus and the Montes Alpes that is critical for a determination of the relation between the major southern and northern peripheral structures concentric to the Imbrium basin. The Alpes and Caucasus-Apennines have been described by some as part of the same structure that has been offset by strike-slip faulting in the gap. Page shows that this is unlikely because structures in the gap are mostly normal faults. The Alpes probably represent the same structure as the rugged terra on the south side of Archimedes, and the gap represents a continuation of the low shelf between this rugged terra and the Montes Apenninus.

G. E. Ulrich, mapping the J. Herschel quadrangle, has observed dark materials that appear to be young volcanics. These materials have also been observed in the Plato and Cassini quadrangles. Page has found thin dark materials covering bright slopes which have long been believed to be sites of relatively recent exposure of fresh materials. Ulrich compares the rims of probable source craters of the dark materials with the rims of terrestrial craters and concludes that relatively more pyroclastic material was ejected from the lunar craters than from the Pinacate craters of northern Mexico, which have collapsed extensively. Other lunar craters that lack dark halos or have low rims are probably more like the Pinacate craters.

The supplement includes maps of two quadrangles, Maurolycus and Rheita, in the southeast quadrant of the Moon. This is an area of complex structure, distant from known mare basins; thus, stratigraphic relations are difficult to determine. A sequence of relative age can be derived for crater materials on the basis of apparent freshness, and an age sequence for plains-forming materials can be derived on the basis of density of superposed craters; however, the two kinds of materials can be related only locally. Rugged terra materials are of unknown origin and age, though some may be related to very old obscure basinlike structures. The stratigraphic units recognized in these areas have only tentatively been correlated with the standard lunar time-stratigraphic systems, whose type areas are in the vicinity of Mare Imbrium.

Three quadrangles at a scale of 1:500,000 are included in the map supplement. The program of mapping 1:500,000 quadrangles is largely experimental: (1) it tests possible advantages in portrayal of geology at the larger scale, (2) it tests the degree to which telescopic data can be extended to larger scales, and (3) it gives new mappers the opportunity to devise new stratigraphic conventions and to express new interpretations. One innovation is the omission of system designations (Imbrian, Eratosthenian, Copernican); the columnar sections show local rock-stratigraphic units uncorrelated with Moon-wide time-stratigraphic units. However, most of the rock units that have been recognized are similar to those recognized in 1:1,000,000 mapping.

In a detailed study of linear structures in the Triesnecker-Hipparchus region using ACIC 1:500,000-scale base charts (shown in text figures, not in the supplement), T. W. Offield has defined and interpreted probable relations of structures to mare basins, to a lunar grid, and to other regional structures. Many structures that are radial and concentric to the Imbrium basin and radial to the Serenitatis basin are present, and some may be radial to Tranquillitatis and Nectaris. Genetic relation to the basins is implied by the geometric relations, though this cannot be proved in this restricted area. Many remaining structures are partly related to a previously recognized lunar grid, but the peak azimuths differ in this area from that grid. Detailed examination of the possible grid structures shows that earlier explanations in terms of Moon-wide stresses are not satisfactory. Other strong systems, that may not be part of a Moon-wide grid, are one that trends N. 0°-15° E. and another that trends within 15° of E.- W. These systems are relatively young and may result from relatively late regional tension that differs from earlier stress fields and may be independent of any Moon-wide stresses. This conclusion is similar to that advanced by G. I. Smith and points to change and migration of the lunar stress and strain fields.

Section III

The studies discussed in section three, "Lunar and Planetary Physics," encompass all of traditional astronomy and astrophysics that pertains to planets and satellites whose visible surfaces consist of materials partly or wholly in the solid phase. As such, some of the studies bear an engineering relationship to extraterrestrial geologic mapping, whereas others are directed toward solution of certain phenomenological problems of astronomy. Examples of the first category are: (1) development of techniques for spatial filtering of imagery; (2) testing application of moiré patterns to study of terrain lineations; (3) development techniques for employing photoclinometry in terrain analysis; and (4) mapping the absolute normal albedo of the moon. The other category includes observational and theoretical studies of the thermal infrared emission of the lunar nighttime surface. The study of the moon's polarization properties has application in both areas.

The earliest theories of the lunar heat flow from diurnal insolation of the Moon's surface consisted of a system of equations describing ordinary heat conduction and a boundary equation conserving solar radiative power input. More recent attempts to incorporate intergranular radiation into the problem have consisted of the introduction of an additive term in the thermal conductivity, previously held constant, which is proportional to the cube of the temperature. R. L. Wildey demonstrates that this approach is in general adequate only when the radiation field is isotropic. The system of equations describing the general problem of heat conduction plus intergranular radiation near a boundary is derived. The solution of the equations is still under study. Their applicability to the lunar surface rests on the assumption that the surficial material is sufficiently fine grained that a unique temperature can be defined within a volume unit whose proportioning between conduction and radiation is close to a statistical average, thus affording treatment of the lunar soil as a continuum.

N. J. Trask presents the results of measurements of the degree of polarization of light from 24 points on the Moon's surface as a continuation of a program of determination of the polarization properties of lunar geologic units. Forty-four points have now been measured. Chief interest attaches to units with lowest albedo; generally, they have the highest and greatest range of maximum polarization values. However, the polarization values of some of these units are the same as or lower than those of nearby higher albedo units, which suggests that maximum polarization depends on some factor in addition to albedo, probably grain size. The Surveyor I landing site is notable in having the highest maximum polarization of any point measured.

R. L. Wildey has begun a developmental program in the spatial filtering of images whose immediate goal in this report period has been the removal of the line pattern in photographed video without the loss of information or the introduction of spurious effects. A primary problem in devising optical systems which alter the relative harmonic coefficients in a two-dimensional Fourier integral representation of a photograph (considered as a functional form of brightness versus two space coordinates) is presented by the coherence of the light sources used to obtain a plane waveform. A Fourier series is truncated by the finite entrance pupil of the of the optical processing system. The ringing effects that result prevent application of the technique to imagery. A device has been built to alleviate this problem, and it has been used successfully in the processing of Ranger spacecraft imagery of the lunar surface. Only a very partial destruction of coherence is desirable in order to avoid information loss. Other applications of spatial filtering that are being studied include seeing compensation, lineation suppression and enhancement, and selection and location from imagery of predetermined geometric forms.

David Cummings and H. A. Pohn have investigated the application of moiré patterns to photogeology. By superposing a ronchi screen over lunar photographs, lineaments inherent in the photographs are enhanced. Rotating the screen reveals the various lineaments present. This technique provides a rapid and inexpensive method for detection of subtle lineaments.

A. J. Swartz is working on an improved system for processing photoclinometric data. The primary goal of this system is to maximize the ratio of work done by the computer relative to manual reduction. This is achieved by a statistical sorting of the calibration data entirely on the computer in place of currently employed manual calibration.

A map of the thermal surface brightness of lunar regions darkward of the sunset terminator, together with a chart showing the position of a large number of nighttime hotspots, has recently been made by telescopic reconnaissance in the 8-14μ region by R. L. Wildey in collaboration with B. C. Murray and J. A. Westphal of the California Institute of Technology (Jour. Geophys. Research, in press). In this annual report, R. L. Wildey presents nine additional thermal anomalies and a morphological analysis of the signal properties of these anomalies. The extraction of information by this process has been carried to the limit allowed by system noise. Attempts to regain the cooling curves of anomalies themselves provide information suggestive that the anomalies are not all volcanic, a fact previously suspected but never observed directly. In addition, it may be concluded that two categories of anomalies are present on the Moon's dark side, not including "false" anomalies of the "delayed sunset" type in which surface prominences are illuminated for some time after sunset on the surrounding lowlands.

H. A. Pohn and R. L. Wildey have produced a map of the normal albedo of the Moon through the observation of real-time photoelectric calibration of many points on the Moon as it was photographed at a phase angle of $1\frac{1}{2}°$. The photoelectric observations are on the Johnson-Morgan UBV system. The photographic emulsion-filter combination used is a poorer approximation to the Johnson V magnitude spectral bandpass than that commonly used for stellar photographic V. However, the spectroscopic emulsion used in the stellar case is unnecessarily grainy and too fast for a photometric exposure under present limitations. The uniformity of color of the Moon, however, is much greater than that of a field of stars. Insignificant errors, due to color effects, are therefore introduced upon calibration. The plate was brush developed to ensure high uniformity in spatial response. The photographic plate was transcribed as a density map at a scale of 1:5,000,000 using a Joyce-Loebl Beckman Whitley combination densitometer and code tracer. The random error across the map is about 1 percent.

Section IV

The fourth section of Part A, by D. E. Wilhelms, summarizes the results of the lunar geologic mapping program of the Geological Survey as of mid-1966. Included are geologic results of mapping 28 quadrangles in the equatorial belt by telescopic means at a scale of 1:1,000,000. Not included are the results of mapping at larger scales from Lunar Orbiter photographs. The paper discusses nearly all stratigraphic units which appear on preliminary versions of the 28 maps and on final versions of 12 of these that were published or in press as of mid-1966. The paper also gives the principles underlying lunar geologic mapping and attempts to show how the geology of the Moon has been partly worked out before man sets foot on its surface.

Areas are mapped that are interpreted as the surface expression of underlying three-dimensional rock-stratigraphic units. The rock units are arranged in order of relative age in a stratigraphic column. The column is divided provisionally into four parts: pre-Imbrian materials, and the Imbrian, Eratosthenian, and Copernican Systems. In pre-Imbrian time many large craters and mare basins formed that are now subdued, heavily cratered and faulted, and partly or completely buried by younger materials. The Imbrian Period began with the formation of the Imbrium basin; the youngest basin, Orientale, formed later in this period. In Imbrian and also probably pre-Imbrian time, the basins, their peripheral structures, large craters, and other depressions were filled by plains-forming materials that are now light (moderate to high albedo) and are probably composed largely of volcanic flows. Possibly simultaneously with emplacement of the plains-forming materials, the terrae were mantled by related materials that are now light, probably pyroclastics and mass-wasted debris. Toward the end of the Imbrian Period a great volume of dark plains-forming materials (mare materials) nearly completed filling of the older depressions, and dark materials mantled the terra in some places. All through the Imbrian Period craters formed, and many of these are partly buried by light and dark plains-forming and terra-mantling materials. In the Eratosthenian and Copernican periods additional dark plains-forming and terra-mantling materials formed, though probably in lesser quantities than in the Imbrian, and other materials formed domes and other features with intrinsic positive relief. Craters formed in these periods are rayless (provisionally, Eratosthenian) and light rayed or dark haloed (provisionally, Copernican). It is concluded that the lunar crust is largely a succession of interstratified plains-forming materials of volcanic origin, relatively thin mantling materials of mixed origin, and crater materials predominantly of impact origin.

SUMMARY OF PART B

In a final report on the detailed field investigation of the Flynn Creek structure in east Tennessee, D. J. Roddy concludes that the structure was most likely formed by the impact of a large meteorite or comet. The crater, which was later filled with Upper Devonian shale, has as major structural elements a zone of highly deformed rim strata surrounding a crater-shaped depression and an uplifted mass of intensely deformed rock in its center.

Flat-lying Middle and Upper Ordovician limestones surrounding the crater have been irregularly uplifted 30 to 150 feet in the rim and are moderately to tightly folded. Folding has caused as much as 35 percent radial shortening. Types of rim deformation include normal faults, thrust faults and asymmetric anticlines, and synclines and monoclines, all approximately concentric to the crater walls. Part of the southeastern rim has been thrust up and away from the crater and partly overrides a large tilted and folded graben. A chaotic limestone breccia composed of material ejected during formation of the crater now overlies the graben and covers part of the ground surface that was present when the crater was formed.

The crater floor is underlain by a chaotic limestone breccia with fragments derived from the same rock units now exposed in the rim. Fragments range in size from less than a fraction of an inch to 300-foot blocks. In the center of the crater a sequence of highly deformed Middle Ordovician limestone and dolomite of the Stones River Group and Lower Ordovician limestone and dolomite of the Knox Group rises nearly 300 feet above the crater floor. Knox strata are raised as much as 1,000 feet above their normal position and locally contain shatter cones.

Breccia contacts with folded rim strata are sharp in some parts of the rim but are jumbled and gradational in other parts. Intense twinning in calcite is common in an irregular zone a few feet to several hundred feet wide adjacent to the crater wall in the deformed rim. Microtwinned lamellae are common in the deformed calcite, and kink bands occur in some crystals.

A thin sequence of marine bedded breccias and dolomite was deposited in the crater during early Late Devonian time and covered by the Chattanooga Shale, the lower unit of which is 300 feet thick in the crater. Lower Mississipian chert and limestone were later deposited in the area.

A search for high-pressure polymorphs and for volcanic or meteoritic material was unsuccessful. A detailed gravity study indicates that no gravity anomaly on the level of 1 milligal is associated with the crater at Flynn Creek. Magnetic studies also show that there are no large magnetic anomalies associated with the structure.

Structural comparisons between Flynn Creek crater and maars and diatremes show little or no similarity in types of deformation. Consideration of volcanic gas-phreatic eruption processes suggests that brittle fracture should accompany cratering with relatively little folding in the rim strata, unlike the deformation at Flynn Creek. Structural comparisons between Flynn Creek crater and craters formed by meteorite impact, nuclear explosion, and chemical explosion show good agreement in nearly all types of deformation. A recently formed, large chemical-explosion crater in Canada has both a central uplift and deformed rim very similar to those at Flynn Creek crater. Similarities in structural deformation between shock-produced craters and Flynn Creek crater suggest an origin by meteorite or comet impact.

Detailed mapping of the Sierra Madera structure in west Texas was continued by H. G. Wilshire. Lithologies of Permian rocks at and near Sierra Madera were determined from field studies and logs of deep drill holes. A new formation was found that is of postdeformation age and is composed of breccia derived from at least two formations.

Examination of thin sections of Sierra Madera breccias revealed internal structures such as microshattering and flow banding of the groundmass that indicate a deformational origin. Megascopically similar breccias from the Glass Mountains lack these features and are considered to be of sedimentary origin.

Structural data from deep drill holes indicate about 1,000 feet of structural relief on the Word-Leonard contact and about 200 feet on the Leonard-Wolfcamp contact at Sierra Madera. These data also indicate that all parts of the Sierra Madera structure are uplifted above the regional trend of the formations. Two drill holes straddling the outer rim of the structure penetrated a deep structure that is displaced laterally from the zone of maximum uplift at Sierra Madera.

The concept of a central core of megabreccia in the structure is considered suspect because part of the boundary of this core is a recognizable formational contact and the character of deformation does not change across the proposed boundary.

A reconnaissance study of the Manicouagan Lake structure in Quebec was made by S. H. Wolfe. Preliminary mapping and petrographic studies suggest that the structure was formed by impact. The textures of deformed rocks in the area are similar to those produced by shock-loading rocks in the laboratory.

The materials in and around missile impact craters in cohesive materials are classified by H. J. Moore in six units with differing properties: target material, thick ejecta, thin to discontinuous ejecta, tilted and broken target material, shattered target material, and slope material.

Missile impact craters are the same size as craters produced by chemical explosives detonated at shallow depths when the kinetic energy of the missile equals the TNT energy equivalent of the explosive. However, for missiles with low specific energies, the comparison is probably not valid.

Larger blocks may be ejected from larger craters if the rocks are well indurated and relatively unfractured.

H. J. Moore and F. G. Robertson studied hypervelocity impact craters in pumice. They found that the sum of ejected material and fragmented material removed from craters produced in pumice by hypervelocity impact is proportional to the momentum of the projectile and 1/8 power of the ratio of the target density and projectile density. This result, which may represent a transition from low velocity to hypervelocity phenomena, is in marked contrast with such data on craters in most metals and basalt which are essentially energy dependent.

Size distribution and petrographic studies are consistent with the results and indicate that irreversible energy losses due to fragmentation and heating have produced the momentum dependency of the amount of ejected material and fragmented material.

Spalling produces larger craters than would be expected when the kinetic energy of the projectile exceeds a certain value.

A new compilation of data on craters produced by explosives was begun by F. G. Robertson using a format modified from the most complete previous work. From this work and from other sources, data on a total of 1,246 craters have now been collected for which there is sufficient information concerning the explosive and the resulting crater. The information has been further standardized for recording on punched cards, so that machine processing can be used for sorting, plotting, and computational purposes.

Diagnostic criteria have been established by E. C. T. Chao for progressive stages of impact metamorphism on the basis of petrographic work on material from Meteor Crater, Arizona; Ries crater, Germany; Lake Bosumtwi crater, Ghana; Wabar crater, Saudi Arabia; and the Henbury craters, Australia.

Unique microstructures, selective phase transitions, formation of vitreous phases without evidence of viscous flow or vesiculation, high-pressure polymorphs, and other evidence of extremely high pressures are considered to be characteristic of hypervelocity meteorite impact metamorphism.

E. C. T. Chao, E. J. Dwornik, and C. W. Merrill report the discovery of nickel-iron spherules in the Aouelloul glass, which is associated with the Aouelloul crater in Mauritania, Africa. Analysis of the spherules by electron microprobe showed that they are meteoritic in origin. Their occurrence in the Aouelloul glass is therefore regarded as proof that the glass is an impactite of terrestrial origin and that the Aouelloul crater was formed by impact of a meteorite.

Poulter Laboratories of the Stanford Research Institute (T. J. Ahrens and D. D. Keough) and the Branch of Astrogeology (D. J. Milton) have started a cooperative program for explosive shock experiments on rock outcrops from which samples can be recovered. Field experiments can be done on a larger scale than laboratory experiments, thus permitting pressure pulses of longer duration. Moreover, the elimination of shock reflections from sample and container boundaries will allow more precise calculation of shock pressures and temperatures. The critical factor in design of the experiment is planarity of the shock front. Smear photography of the detonation of the prototype assemblies indicated that detonation instantaneous within ± 1 microsecond occurred over the entire explosive pad. The shock wave produced is satisfactorily planar to be used in field experiments.

A study of the influence of stress history on low-temperature thermoluminescence of halite and applications of thermoluminescence techniques to geologic problems was made by C. H. Roach.

Electron traps produced by strain can produce low-temperature thermoluminescence in halite which has been exposed to X-ray irradiation and heated from -196° to 0°C. The traps and associated low-temperature thermoluminescence are related to plastic deformation of the halite caused experimentally by both low and high rates of applied stress. Field studies show that high rates of strain associated with nuclear and chemical explosions also produce low-temperature thermoluminescence in halite which is related to the associated plastic deformation. Single-crystal X-ray studies show that deformation of the halite crystals is associated with the stress-induced low-temperature thermoluminescence.

The thermoluminescence techniques developed on this research program should have great application to the science of rock mechanics and, of course, to numerous related geological problems. These techniques would be especially well suited to study of 1) slow creep and plastic deformation associated in origin with large earthquakes, (2) plastic deformation of rocks in areas severely deformed by various tectonic processes, and (3) plastic deformation in contact-metamorphosed rocks adjacent to some igneous intrusions and in regionally metamorphosed rocks.

Moses Rock diatreme, in San Juan County, Utah, has been studied by Thomas R. McGetchin. The diatreme is a dikelike intrusion about 1,000 feet wide and more than 4 miles long. At the present level of exposure, it cuts rocks of the Permian Cutler Formation, but the ground surface at the time of emplacement may have been at least 3,000 feet higher. The intrusion consists of intrusive serpentine breccia and minette, sedimentary inclusions derived from Mesozoic and Paleozoic strata, and fragments of Precambrian metamorphic and igneous rocks derived from the basement rock. Size analysis of inclusions showed, for fragments derived from below the present surface, that the depth of source is correlative with the maximum block size of a particular lithology; this relationship allows reconstruction of the section where the stratigraphy is not known. The original surface expression of the diatreme was probably a long rift with several maar-type craters along it, resembling such lunar rilles as Hyginus and the prominent one in the eastern part of the floor of Alphonsus.

SUMMARY OF PART C

Electron microprobe analyses by Robin Brett indicate that Ni-Fe spherules within impactite glass bombs from the Meteor Crater area, Arizona, contain from 20 to 65 wt percent Ni. Spherules from impactite glass at Wabar crater, Saudi Arabia, contain 8 to 41 wt percent Ni. The parent meteorites contain 7 to 8 wt percent Ni. The analyses indicate that glass in the vicinity of the spherules is enriched in Fe. Spherules in philippinite and indochinite tektites contain 1 to 3 and 4 to 6 wt percent Ni, respectively. The glass in the vicinity of tektite spherules is not enriched in Fe and contains from 3 to 6 wt percent Fe.

Brett proposes that spherules in impactite glasses were partially oxidized prior to or during incorporation into impactite bombs. The almost Ni-free Fe oxide diffused into the glass, thus depleting the metal in Fe, and enriching the glass. Dolomite and water may have contributed to the oxidation at Meteor Crater.

Spherules in tektites were not oxidized because the tektites were formed in an atmosphere with extremely low fugacity of oxygen. A less likely alternative is that the spherules were incorporated into the tektite glass instantaneously so that oxidation was prevented.

Seven Georgia tektite specimens (selected to cover the range of specific gravities) and the Martha's Vineyard tektite were chemically analyzed by F. Cuttita, R. S. Clarke Jr., M. K. Carron, and C. S. Annell for all the major and 21 minor elements. Their major and minor element composition is comparable with that of the silica-rich bediasites. The new data show a continuous range of variation for SiO_2 (79.8-83.6 percent), Al_2O_3 (9.5-11.7 percent), FeO (1.82-3.09 percent), and TiO_2 (0.42-0.56 percent). Continuity of the compositional variations of all the North American tektites, their general geographic association, and identical K-Ar ages of 34 ± 1 million years strongly suggest (1) that the Georgia and Martha's Vineyard

tektites represent the high-silica end-members of the continuous range of compositional variations exhibited by the North American tektite family, and (2) a common origin both by event and parent body for the Texas, Georgia, and Martha's Vineyard tektites. These natural glasses could have formed by fusion and differential volatilization due to meteoritic impact on a target area of siliceous igneous rocks.

Robin Brett and E. P. Henderson (U.S. Natl. Mus.) have completed a study of lamellar troilite in iron meteorites. They find that a number of iron meteorites contain elongated inclusions consisting predominantly of troilite, which have been termed Reichenbach lamellae. Two types of inclusions exist, the first up to 6 cm long and 0.2 mm wide, the second up to 2 cm long and 3 mm wide. The first type contains troilite with subordinate daubreelite and is commonly rimmed by schreibersite and swathing kamacite; the second consists largely of troilite with daubreelite and rare graphite and silicate grains. Both types formed from a residual sulfide melt after the solidification of Ni-Fe metal. Swathing kamacite surrounding troilite in iron meteorites formed by nucleation at the troilite-metal interface during the formation of the Widmanstätten texture. Meteorites containing troilite inclusions of the second type appear to have cooled more rapidly than most iron meteorites.

A sounding rocket payload, designed to collect micrometeorites at the outer fringes of the earth's atmosphere, was successfully launched and recovered by Ames Research Center on November 16, 1965. M. H. Carr and H. J. Gabe of the U.S. Geological Survey participated in the experiment by designing and examining one of the several sampling modules flown. Electron microscopic examination of grids exposed during flight showed that an extremely small number of particles were collected. Some of these may have been contaminants from the vehicle itself. The maximum possible particle flux above the atmosphere was estimated and found to be less than the flux calculated from the Venus Fly Trap experiment and also less than the flux calculated from satellite data.

Irving May and Frank Cuttitta have reviewed the newer analytical techniques available in geochemical research. Specific techniques covered are chromatography, activation analysis, fission track analysis, Mössbauer spectrometry, atomic absorption spectrometry, optical emission spectrometry, and X-ray fluorescence spectroscopy.

A neutron activation procedure for the simultaneous determination of Cs, Hf, and Ta has been developed by Paul Greenland. The procedure is a semi-instrumental one in that only limited radiochemical separations are employed. The useful sensitivity limit is about 0.01 ppm for each of the elements in a 100 mg sample. Greenland proposes to use the method in analysis of volatilization experiments and in analysis of tektites.

Charles Annell has developed a procedure for quantitative analysis of zinc and silver in silicates using a 25 ampere d-c arc in an argon atmosphere. The Zn 3345.02 line is used down to 4 ppm, and either Ag 3383.0 or Ag 3280.6 line down to 0.2 ppm. The spectra are recorded on Eastman III-0 plates using a grating spectrograph. Using 20 mg samples, analytical results are comparable to those obtained by conventional chemical methods. The method will be used in future tektite, meteorite, and rock analyses.

SUMMARY OF PART D

Results of analysis of the more than 17,000 photographs returned by the three successful Ranger spacecraft are described by N. J. Trask. At intermediate to large scales (1:500,000 to 1:50,000), the surface materials photographed can be divided into units with differing characteristics. Plains-forming materials in particular exhibit sharp contacts between units with contrasting frequencies of craters and small differences in surface textures. The engineering properties of these various units may differ enough to necessitate accurate mapping from photographs returned by Lunar Orbiter and other remote sensing instruments.

Crater statistics suggest that the uppermost surface of all exposed units consists of fragmental debris produced by the continued impact of both primary and secondary fragments. Studies of crater morphology suggest further that the cratering history of the Moon has departed slightly from a simple steady state development, in which a constant flux of impacting objects destroys old craters at the same rate as new craters are formed.

Geologic maps prepared from Ranger photographs are included in the map supplement to Part D. These maps cover the Sabine region (RLC 7), mapped by H. G. Wilshire; the Sabine DM region (RLC 9), mapped by N. J. Trask; and the Alphonsus region (RLC 14), mapped by M. H. Carr.

Photogrammetric research by J. D. Alderman and S. C. Wu was directed toward modification of procedures and equipment used in anaglyphic projection and analytic plotter (AP/C) programs for processing Ranger vidicon imagery.

Standard anaglyphic plotters were modified for the unconventional stereo imagery and to accommodate the highly variable geometry of the Ranger flight trajectory and camera attitude. A ratio printer was designed and constructed to produce diapositives at the correct scales. No consistent results were obtained in the anaglyphic stereo models when the same model was reconstructed by different operators or on different projectors. Poor metric characteristics of the imagery, small image sizes, image smear, and low sun angles all contributed to the poor photogrammetric results.

Some of the Ranger stereo pairs were photogrammetrically reduced on the analytic plotter (AP/C) of the Ohio State Highway Department. Efforts on the AP/C were mainly directed to crater measurement, spot elevation recording for slope computation, and delineation of geologic units. However, experiments with some of the Ranger IX frames showed that both relative and absolute orientation to within a few microns could be achieved independently by different operators. On these models, measured slope values were in good agreement with shadow lengths. This repeatability and internal agreement indicate that line maps can be generated from at least some Ranger stereo photographs. On other stereo pairs, datum appeared to be tilted, warped, or fluid, and measured slope values did not agree with shadow lengths. The photogrammetric problems of reduction on the AP/C are in part due to the same deficiencies that caused erratic results in the anaglyphic plotters. Also, difficulty in image-point discrimination resulting from low contrast on the diapositives commonly hindered model setup and operation. However, the automatic computational capability of the AP/C overcame many of the deficiencies not eliminable in the simpler analog system.

H. J. Moore has analyzed the fine-scale features of the lunar surface shown in photographs taken by the Ranger spacecraft, Surveyor I, and Russia's Luna IX, and has found that craters ranging from a few centimeters to several hundred meters across predominate. Positive features such as blocks, clods, and fragments become increasingly abundant with increasingly finer scale until, at a scale of a few centimeters, they are common features of the lunar landscape.

The large range in size of craters as well as their size-frequency distribution are consistent with the notion that the craters were produced by impact of objects from space and debris from other craters. Comparison between the photographs of the lunar surface and photographs of a surface produced experimentally by repeated impact of projectiles of various sizes shows that small lunar craters can be worn down by repeated impact of debris from space and by ejecta from larger craters. To an approximation, many lunar surfaces may have reached a "steady state" in which craters are destroyed as rapidly as they are formed. In this steady state, the surface is characterized by craters within a given size class that range from fresh appearing craters with well-defined rims to rimless craters which appear to be worn down and filled in. Comparison of the morphologies of small craters on the lunar surface with those produced by experimental impact and chemical explosives shows that the uppermost part of the lunar surface is composed of fragmental material which is weakly cohesive--somewhat like moist sand. The blocky ejecta scattered around larger craters indicates that solid rock occurs below the surficial layer of fragmental material.

Prior to Lunar Orbiter Mission I, reports were prepared on the geology of the nine primary sites to be photographed during the mission. These reports presented terrestrially derived geologic, photographic, infrared, and albedo data that were then available. Interpretations based on these data were presented on available base maps or in graphs. The site reports were used during the screening of the incoming Lunar Orbiter I photographs and were very useful in plotting the photographs, identifying features, and, generally, in bridging the gap between terrestrial photography and the much higher resolution Lunar Orbiter photography.

A sample of the reports, Site A-1 on the western margin of Mare Fecunditatis, by T. W. Offield, is reprinted in Part D. The other site studies and their authors are as follows:

A-2	E. A. Holm
A-3	M. J. Grolier
A-4	L. C. Rowan
A-5	D. H. Dahlem
A-6	K. A. Howard
A-7	M. N. West
A-8.1	David Cummings
A-9.1	J. F. McCauley